# FINITE ELEMENT MODELING OF COASTAL CIRCULATION

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## LONG-TERM GOALS

To develop finite element procedures for nearshore and shelf-scale operations using unstructured grids which can be adapted in a real-time data assimilative manner. Initial application is to the the Yellow Sea, with technology transfer from parallel efforts in the Gulf of Maine.

## OBJECTIVES

• Develop a realistic circulation model for the Yellow Sea. Processes must include tides and tidal rectification, wind, remote forcing, and baroclinicity.

• Develop and archive climatological circulation for the Yellow Sea, in 6 bimonthly seasons.

• Develop data-assimilative methods for shipboard limited-area nowcasting and forecasting using inverse methods and the above results as prior estimates.

## APPROACH

The work is carried out in collaboration with Dr. Cheryl Ann Blain of NRL. The climatological circulation is computed using full-physics prognostic models. All calculations are fully 3D. Archived physical fields are web served both in raw data and graphical form.

New data-assimilation software and analytical approaches are tested first in the Gulf of Maine context, where the phenomena are well understood and data is relatively abundant; then in the Yellow Sea via Observational System Simulation Experiments. Beta versions of software are distributed within the Quoddy Users' Group for testing and refinement. Mature models and data products are transferred to NRL.

## WORK COMPLETED

We have conducted the first comprehensive study of the 3D climatological circulation in the Yellow and Bohai Seas under the combination of baroclinic, wind, and tidal forcing. The annual cycle is approximated as the transition between a series of six seasonal realizations (centered temporally at January 15, March 15, July 15, September 15, and November 15). The seasonal hydrography is initialized from the MODAS data set (see Harding et. al. 1998 and Naimie 1998) and allowed to prognostically evolve during the simulation, while the wind stress is maintained at seasonal mean values from Hellerman and Rosenstein (1983). The tidal forcing is included through tidal elevation boundary conditions at the open ocean boundary of the model domain. These boundary conditions were inverted using the procedure developed in Lynch et. al. (1998), which minimizes the difference between observed and modeled tidal elevations at observational locations from Blain (1997). Resolution of the finite element mesh nearshore approaches 2 km.

# Report Documentation Page

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We are continuing to develop data assimilative methods and models for use in limited-area nowcasting/forecasting applications. Products to date include an inverse model for extracting tides from ADCP observations (see Lynch et. al. 1998) and a study of errors due to objective analysis of nonsynoptic CTD data (see Lynch and Naimie 1998). An adjoint model is under development for inverting wind-band signals from ADCP data. In December, we will conduct a weeklong workshop focusing on a set of Observational System Simulation Experiments. This activity will facilitate evaluation and improvement of our current methods and strategic plans for ship-based nowcasting/forecasting. Next spring we will conduct shipboard modeling experiments on Georges Bank, aimed at using our forecasts to assist observationalists in tracking zooplankton and larval fish communities as well as dye released into the ocean.

## RESULTS

The seasonal cycle (Fig 3) indicates that January and March exhibit the same basic winter pattern. May is quiescent, followed by July which defines the summer mode. September shows the same general summer pattern, with features shifted westward. November is a transition period followed by winter conditions.

Results for winter and summer exhibit two distinct circulation modes. In winter (Figs 1 and 3), strong northerly wind drives southward flow at the surface and along both Korean and Chinese coasts (Fig 1b). This is compensated by deep return flow – the Yellow Sea Warm Current – in the central trough of the Yellow Sea, penetrating to the Bohai (Fig 1a). The Changjiang discharge exits to the southwest in winter, trapped along the Chinese coast (Fig 1ab). Wind is the dominant forcing mechanism (compare Figs 1d and 3a), with the baroclinic (Fig 1c) and tidal residual (not shown) components being of lesser importance throughout the domain. In summer (Figs 2 and 3), a cold water pool produced by winter cooling is isolated in the deep trough (Fig 2c), setting up cyclonic circulation over the eastern Yellow Sea (Figs 2c and 3d). Summer winds from the south drive northward and eastward flow along the Chinese coast (Fig 2b). The composite summer circulation is a qualitative reversal of the winter pattern. The Changjiang discharge is driven offshore toward the Korean Strait by the summer wind (Fig 2b). The baroclinic forcing (Fig 2c) dominates the eastern Yellow Sea in summer, with wind (Fig 2d) and tidal rectification (not shown) controlling the circulation to the west of the cyclonic gyre. A more complete discussion of these results can be found in Naimie et. al. (1998).

## IMPACT/APPLICATIONS

The combination of the Naimie et. al. (1998) climatology, mature models, and models under development will facilitate demonstration of ship-based nowcasting/forecasting capabilities in the coming year.

## TRANSITIONS

Dr. Cheryl Ann Blain is an active participant on this project. All software developed is available to her and other Navy personnel via www html documents. The Quoddy Users Group is the vehicle for technical discussions and trial of the software in other applications, ensuring a robust conceptual development and software design. All methodological advances are prepared for publication in peer-reviewed media.

## RELATED PROJECTS

USGLOBEC (NOAA/NSF): Georges Bank has been the training ground for most of the soft-

ware development prior to this project. This application is still active and due to the large amount of data for this system, it remains a prime target for initial testing of nearly all project ideas.

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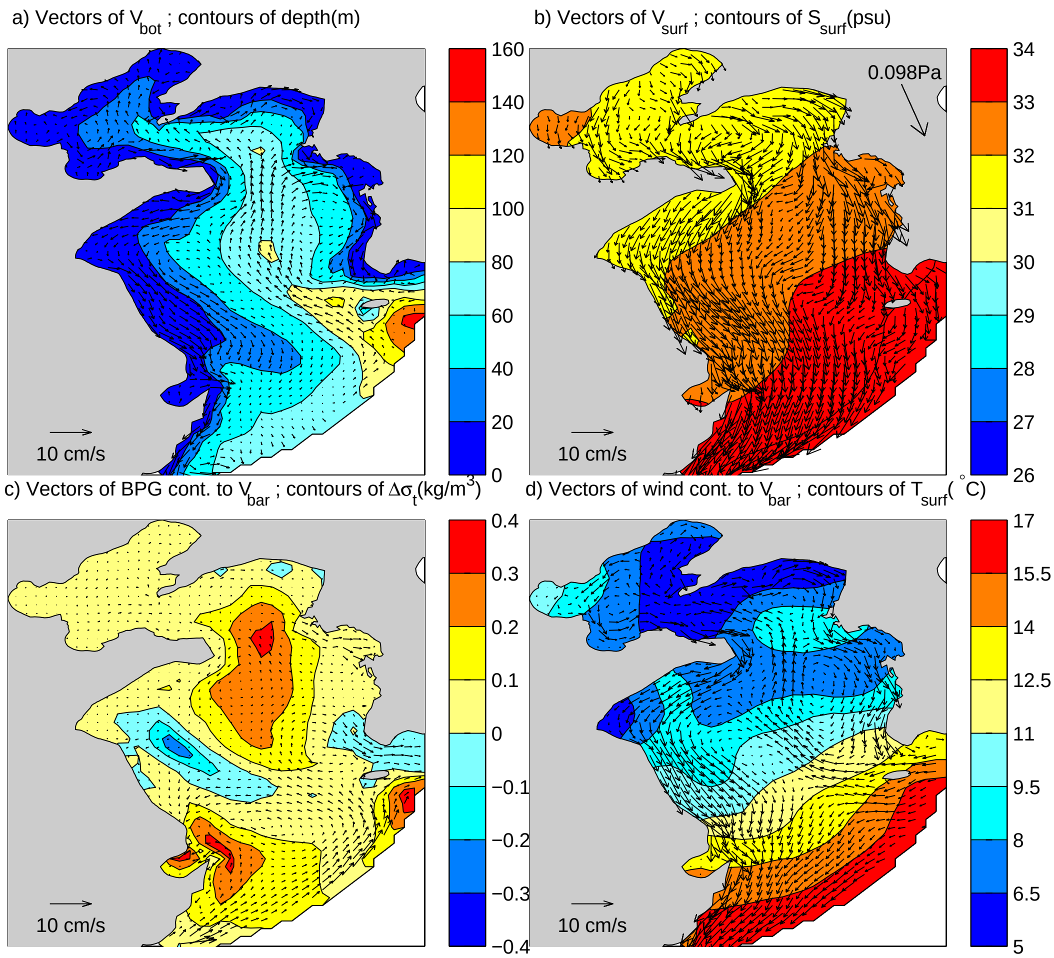


Figure 1: Winter Circulation and Hydrography: a) Near-bottom velocity and contours of bathymetric depth (m); b) Near-surface velocity, contours of surface salinity (psu), and mean wind stress (Pa); c) Contribution to vertically averaged velocity from baroclinic forcing and contours of bottom density - surface density (kg/m$^3$); d) Contribution to vertically averaged velocity from wind forcing and contours of surface temperature (°C)

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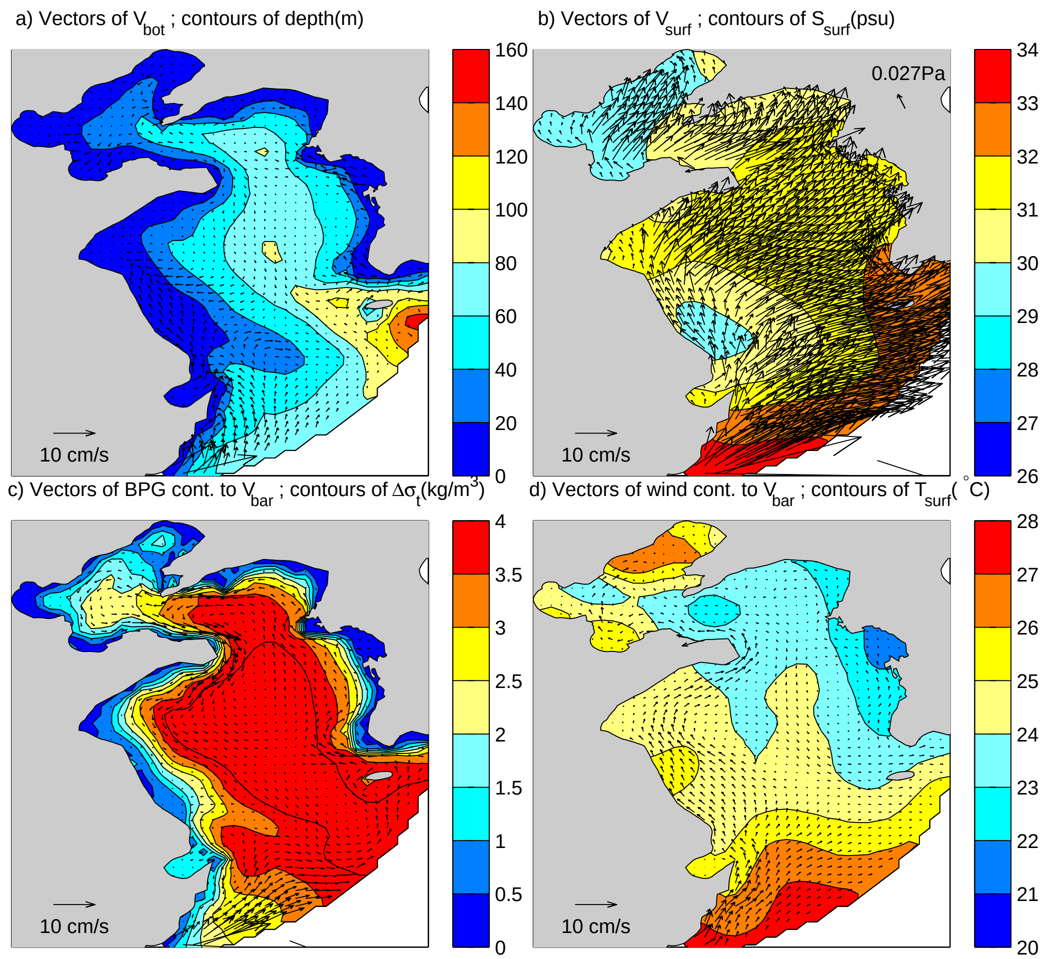


Figure 2: Summer Circulation and Hydrography: a) Near-bottom velocity and contours of bathymetric depth (m); b) Near-surface velocity, contours of surface salinity (psu), and mean wind stress (Pa); c) Contribution to vertically averaged velocity from baroclinic forcing and contours of bottom density - surface density (kg/m$^3$); d) Contribution to vertically averaged velocity from wind forcing and contours of surface temperature (°C)

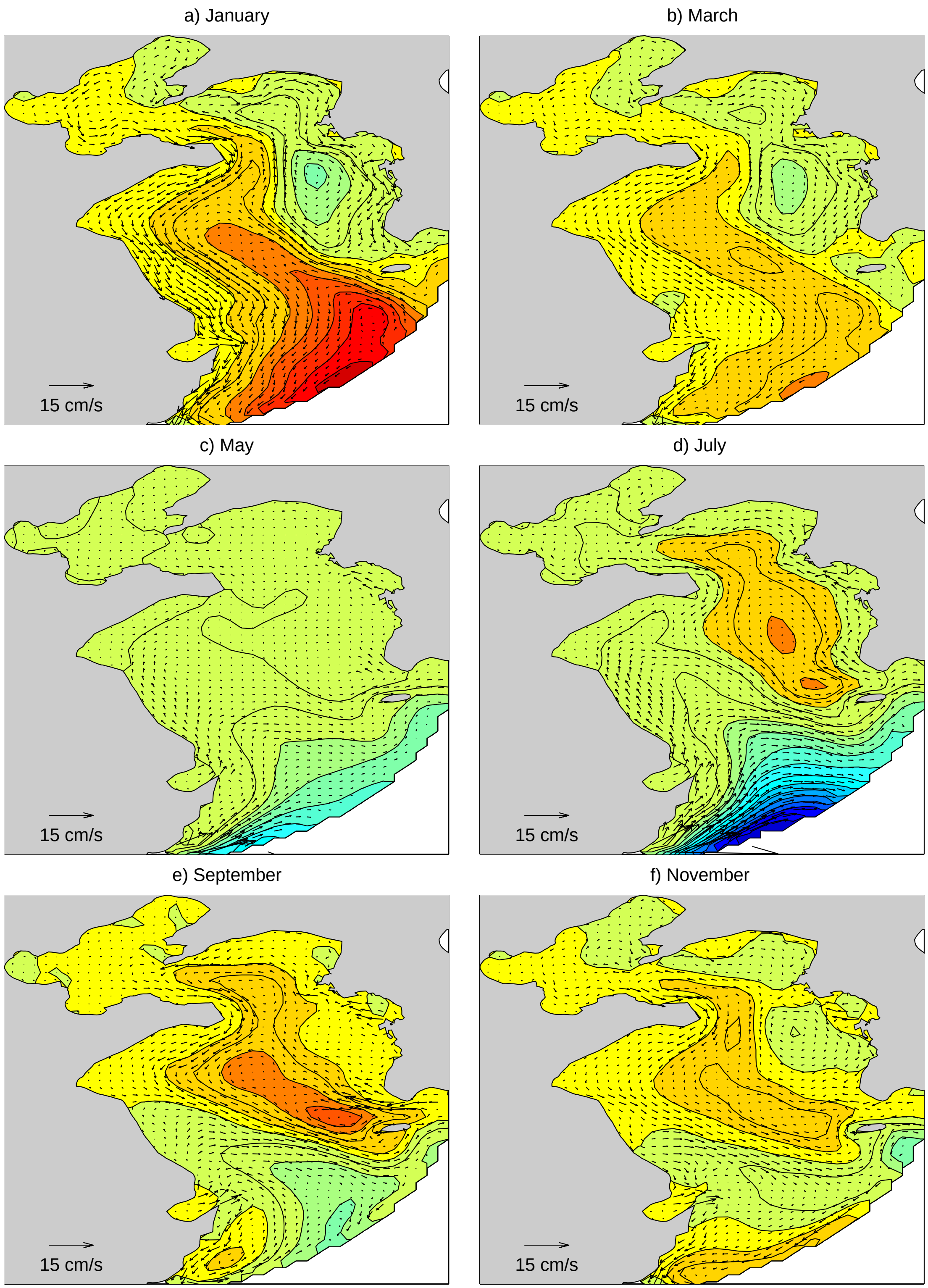


Figure 3: Seasonal Solutions: Vertically averaged velocity and transport streamlines (contour level is 0.5 Sv).